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RESPONSE PREDICTION FOR HUALIEN LSST MODEL BY USING HYBRID MODELLING

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ABSTRACT

This paper presents the analytical predictions for the responses of the forced vibration test on Hualien containment model structure. The predictions were performed blindly by using the computer programs HASSI-8 and LAYSSI which were developed for solving the soil-structure interaction problem using the method of hybrid modelling. The results obtained show very good correlations with the field test results.

KEYWORDS

Soil-structure interaction, model test, forced vibration test, Hualien LSST model, hybrid model, response prediction.

INTRODUCTION

Following the successful Large Scale Seismic Test (LSST) at Lotung, Taiwan, a second-phase Large Scale Seismic Test is carrying out at Hualien, Taiwan. It is an internationally cooperated research program sponsored by NRC and EPRI (US), TEPCO and CRIEPI (Japan), CEA and EdF (France), KINS and KEPCO (Korea) and TPC (Taiwan). In this project, a quarter-scale nuclear power plant containment model was built at Hualien to monitor its seismic responses during strong earthquakes. Hualien is a seismically active area located on the collision zone of the Eurasian Plate and the Philippine Sea Plate. Strong earthquakes occurred very frequently in past times. It is anticipated that some strong earthquake data can be recorded here as a data base for investigating the effects of soil-structure interaction on the dynamic responses of containment structure during earthquakes. Also, it can be used to verify the degree of dispersions among various methodologies having been used in engineering design, and thus to improve the state-of-art in soil-structure interaction analyses.

During the construction of the model structure at Hualien, two phases of forced vibration test had been conducted on the model structure to get the pre-earthquake information about the soil-structure system. Like the Lotung LSST project, round-robin blind predictions for both forced vibration tests of Hualien LSST project were performed by different groups independently before the test results were released. Two hybrid methods, the HASSI-8 (Hybrid Analysis for Soil-Structure Interaction) and LAYSSI (LAYered Soil-Structure Interaction analysis) computer

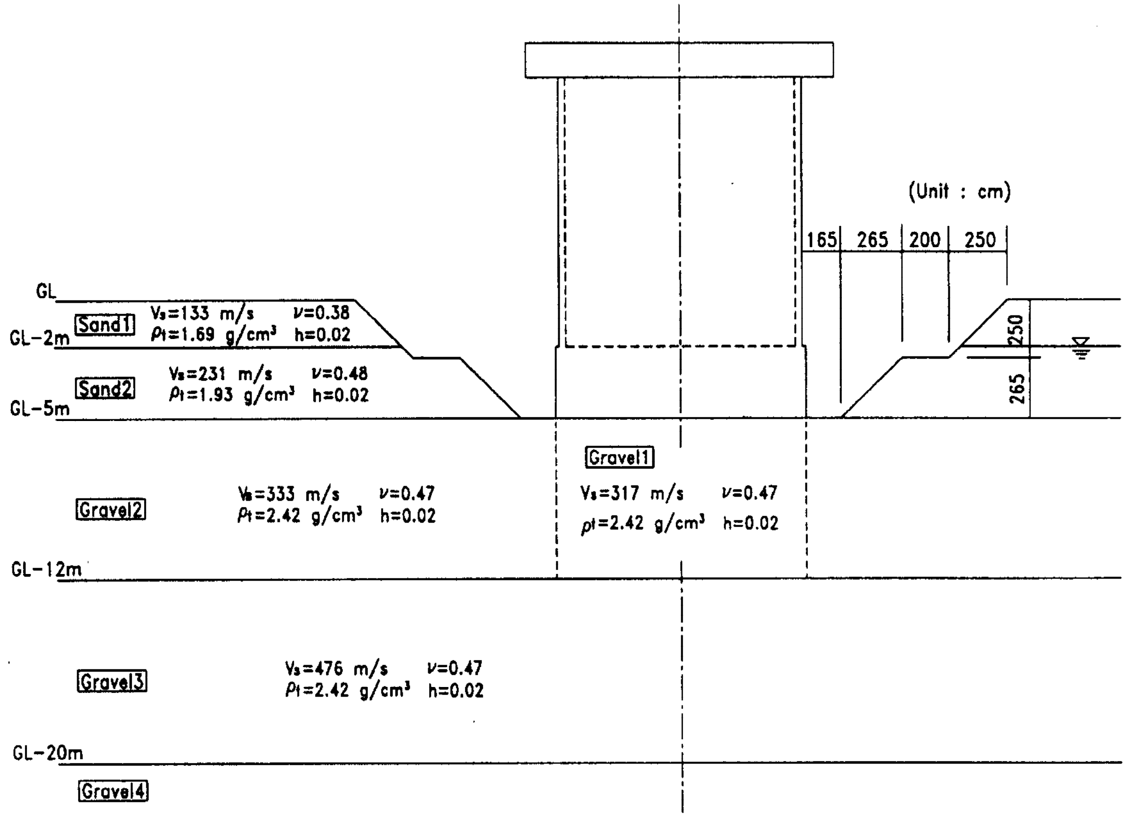


Fig. 1 Unified ground model for FVT-1 analysis

programs, have been selected by the Taiwan group to conduct the analytical predictions and further correlation studies. The purpose of this paper is to compare the results of blind predictions with the field test results.

FORCED VIBRATION TEST BEFORE BACKFILL

The first phase force vibration test (FVT-1) was conducted under the condition when the containment model had been completed but before backfilled, as shown in Fig. 1. The model structure is a hollow cylinder with radius of 526 cm supporting a thick roof slab (thickness 150 cm) and resting on a base mat (thickness 300 cm). The total height of the model is 1613 cm. The test was conducted by TEPCO (1993) by using an eccentric typed shaker. For the horizontal test, the model structure was excited at the roof and base levels, respectively, along its radial direction. For the vertical test, the model structure was excited only at the center of the base. Each test was run at frequency interval of 0.1 $\sim$ 0.2 Hz to give a complete response curve ranged from 2 Hz to 20 Hz.

UNIFIED GROUND MODEL

The geological conditions of Hualien LSST site had been investigated very extensively by the CRIEPI, and an Unified Ground Model, as shown in Fig. 1, was then proposed as the basic ground model for prediction analysis (CRIEPI, 1993). This model shows that the soils from the ground surface down to the depth of 20 meters can be divided into four layers primarily according to the increasing of shear wave velocities with depth. The model structure rests on the surface of gravel formation. To determine the shear wave velocity of the soil underneath the foundation slab, additional geophysical survey was conducted under the existed condition when the containment structure had been completed but without any backfill. Based on the results of measurements and analyses, it has been deduced that the gravels just underneath the foundation slab have an average shear wave velocity of 317 m/sec, a little smaller than the original ground condition due to the effects of constructional works (CRIEPI, 1993).

METHOD OF ANALYSIS

Concept of Hybrid Modelling

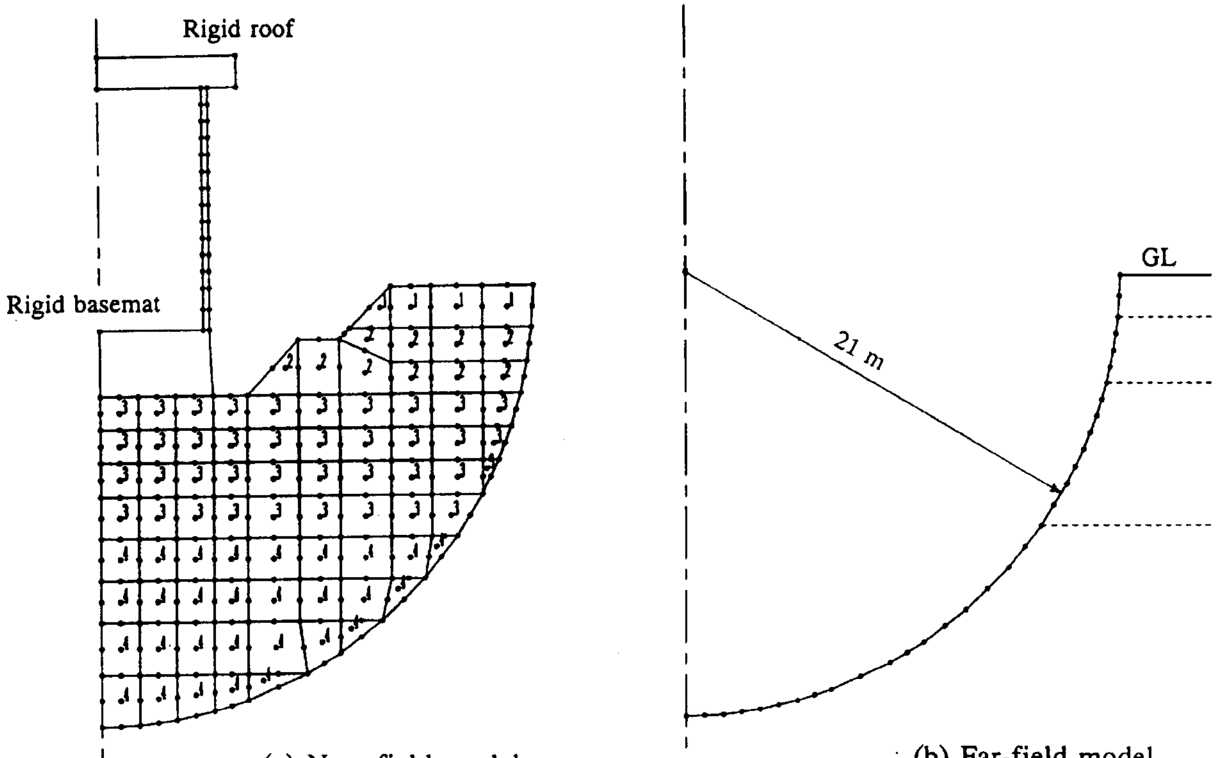
Two methods are adopted herein for prediction analyses. They are the HASSI-8 and LAYSSI modellings which are formulated based on the concept of hybrid modelling. Basically, the hybrid modelling uses method of substructure and frequency domain solution for soil-structure interaction analysis. Its idea is to divide the whole domain of a soil-structure system into a near-field and a far-field by a regularly-shaped interface which cuts through the soil region under the structure. The near-field consists of the structure to be analyzed under prescribed loading conditions and a finite portion of soil encompassing its base, including embedment if present. It can be modelled appropriately in three-dimensional form using finite elements. The far-field is a semi-infinite layered half-space with a surface cavity, which shares a common interface with the near-field. The dynamic characteristics of the soil medium in the far-field are represented by a complex-valued frequency-dependent boundary impedance matrix which is coupled to the finite element near-field through the interface nodal degrees-of-freedom. The impedance of the whole system will be obtained by assembling the impedance matrices of the near- and far-fields. Based on that, both seismic ground motions and externally applied forcing functions can be accommodated as the input excitations to find the time-history response and/or spectrum response of the complete soil-structure system (Gupta, *et al.*, 1982). In this formulation, all calculations are standard once the far-field impedance matrix can be formulated properly to represent the wave motions in the semi-infinite layered media. Both the HASSI-8 and LAYSSI modellings adopt the same procedure described above except for the formulations for the far-field impedance, which will be described subsequently.

HASSI-8 Modelling

The far-field impedance matrix of HASSI-8 modelling is formulated by using the impedance coefficients generated by Gupta *et al.*, (1982). Three sets of frequency-dependent, complex-valued impedance coefficients over the boundary of a hemispherical cavity in an uniform half space have been obtained by using method of system identification and thus can be easily implemented into the program HASSI-8 to formulate the far-field impedance matrix.

To predict the responses of Hualien FVT-1, the HASSI-8 analytical model adopted is shown in Fig. 2. A hemispherical interface of radius 21 m is chosen as the NF/FF interface. The far-field is divided into four layers according to the recommended free-field ground model as shown in Fig. 1. The bottom layer (Layer 4) is regarded as a semi-infinite half-space since the bedrock is very deep so that it will have no SSI effect on the response of the surface structure.

The near-field finite element model adopted for the HASSI-8 modelling is shown in Fig. 2(a). The soil medium in the near-field is modelled by 82 three-to-nine node axisymmetric solid elements. The number in each element indicates the layer of soil in the Unified Ground Model. The model structure is also modelled by axisymmetric solid elements. Since the roof slab and the base mat are very thick, they are regarded as rigid discs in the modelling. The cylindrical wall has a thickness of 30 cm. They are modelled by 7 six-node axisymmetric solid elements. The material properties adopted for concrete are given as follows: density = 2.4 t/m^3, Young's modulus = 2.88×10^5 kg/cm^2, Poisson's ratio = 0.16, damping ratio = 0.02.



(a) Near-field model (b) Far-field model

Fig. 2 HASSI-8 model for FVT-1 analysis

LAYSSI Modelling

The far-field impedance matrix of LAYSSI modelling is formulated by using weighted residual method, in which the approximation functions are chosen from the fundamental solutions corresponding to a set of ring sources properly distributed in the semi-infinite layered halfspace of viscoelastic medium (Lee, 1993).

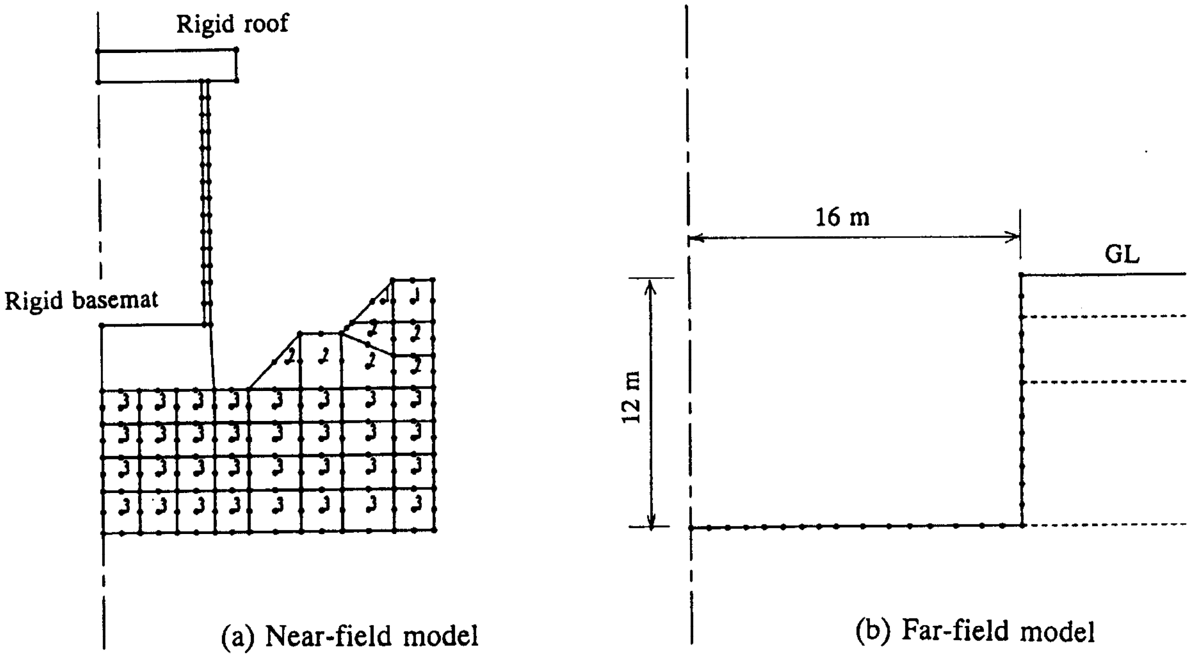
The NF/FF interface can be any regularly-shaped function in this formulation; however, a cylindrical shape is the most convenient one for the Hualien case. The analytical model for Hualien FVT-1 is selected as shown in Fig. 3. It is a hybrid axisymmetric model, in which the far-field is a four-layered half-space with a cylindrical cavity of radius 16 m and depth 12 m, and the near-field consists of the finite element models of model structure and surrounding soils before the backfill condition. In the blind predictions, the soil properties used for the near- and far-field soils are adopted from the Unified Ground Model as shown in Fig. 1. The finite element model adopted for the containment structure is same as the HASSI-8 modelling.

CORRELATIONS OF PREDICTED RESULTS WITH D_2 RESULTS

Based on the analytical model constructed above, the responses were calculated blindly and then compared with the test results afterwards. The correlations between the predictions and the D_2 responses of field test are shown as follows:

Roof Horizontal Test

For the roof horizontal test, the roof horizontal responses predicted by both the HASSI-8 and LAYSSI modellings are compared with the corresponding D_2 responses as shown in Fig. 4. The



(a) Near-field model

(b) Far-field model

Fig. 3 LAYSSI model for FVT-1 analysis

correlations between the blind predictions of both analytical modellings and the field test are excellent in both the amplitudes and the phase angles, except a very small difference existed in the resonant frequency. The predicted value is 4.7 Hz while the D_2 response shows a value of 4.6 Hz. At resonance, the displacement components of swaying, rocking and elastic deformation agree quite well with the test results as shown in Table 1. It shows that the model structure responses primarily in rocking mode. As for the responses of the basemat, they are similar to the roof response but with much smaller amplitude. The responses predicted by both the HASSI-8 and LAYSSI modellings also correlate very well to the field test results, but not shown here.

Base Horizontal Test

For the base horizontal test, the predicted horizontal responses at the roof level are compared with the corresponding D_2 responses as shown in Fig. 5. The blind predictions fit very well to the field test results in both the amplitudes and the phase angles except a very small difference in resonant frequency as mentioned previously. The displacement components of roof response are summarized and compared with the test results in the last two rows of Table 1.

Base Vertical Test

For the base vertical test, the predicted vertical responses in roof level are compared with the test results as shown in Fig. 6. Both the response curves of analytical modelling and field test are rather flat. The peak responses of the field test are distributed in the range of 9 to 11 Hz, while the peak frequency predicted by analytical modelling is around 12 Hz.

CONCLUDING REMARKS

Based on the results presented herein, it can be concluded that both the computer programs HASSI-8 and LAYSSI are very effective in modelling the dynamic responses of the containment model structure under forced vibration tests. The predicted response curves of amplitudes and

Table 1 Comparison of Displacement components in roof horizontal response

Position Direction	Excitation Dir.	Pos.	Natural Freq.(Hz)	Damping Ratio(%)	Rocking Displ.	Elastic Displ.	Swaying Displ.	Total Displ.
RF(Record) D2	D2	Roof	4.6	3.7	155.9 (65.62%)	53.3 (22.43%)	28.4 (11.95%)	237.6
RF(HASSI8) D2	D2	Roof	4.7	4.5	134.6 (70.18%)	41.3 (21.53%)	15.9 (8.29%)	191.2
RF(LAYSSI) D2	D2	Roof	4.7	3.2	170.5 (69.25%)	53.9 (21.89%)	21.8 (8.86%)	245.8
RF(Record) D2	D2	Base	4.6	3.7	40.71 (66.14%)	13.74 (22.32%)	7.10 (11.54%)	61.55
RF(HASSI8) D2	D2	Base	4.7	4.5	30.59 (70.08%)	9.34 (21.40%)	3.72 (8.52%)	43.62
RF(LAYSSI) D2	D2	Base	4.7	3.2	39.48 (68.92%)	12.40 (21.65%)	5.40 (9.43%)	57.06

phase angles fit very well to the field test results in the frequency range interested. Small discrepancies existed near the peak responses may be due to the uncertainties of soil moduli and dampings that can not be accurately determined so far.

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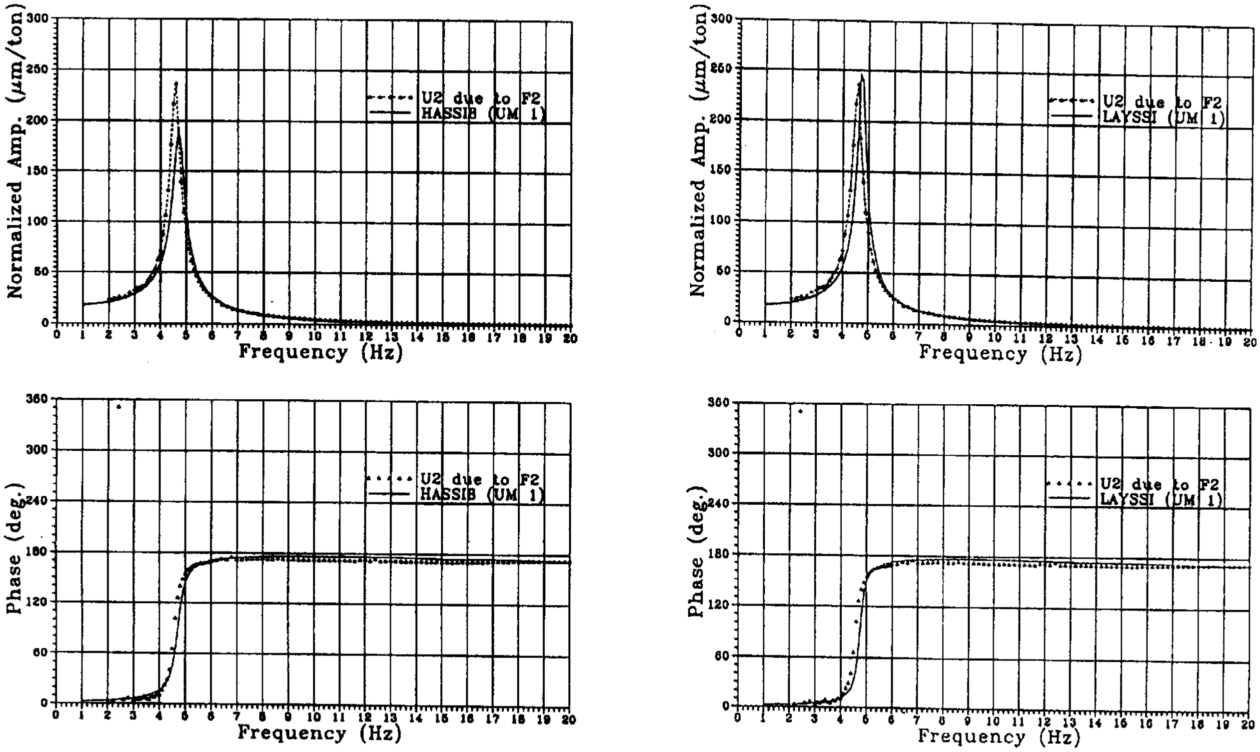

Fig. 4 Comparisons of roof horizontal response in roof horizontal test

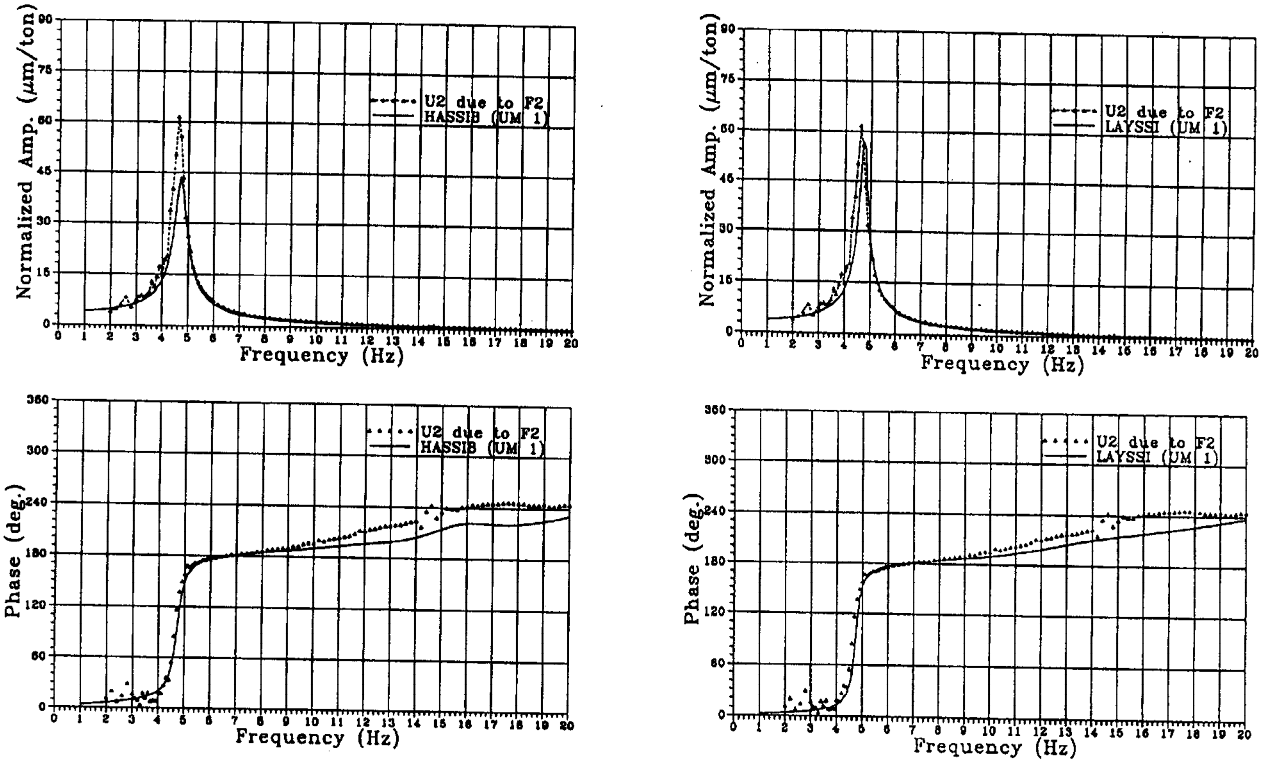

Fig. 5 Comparisons of roof horizontal response in base horizontal test

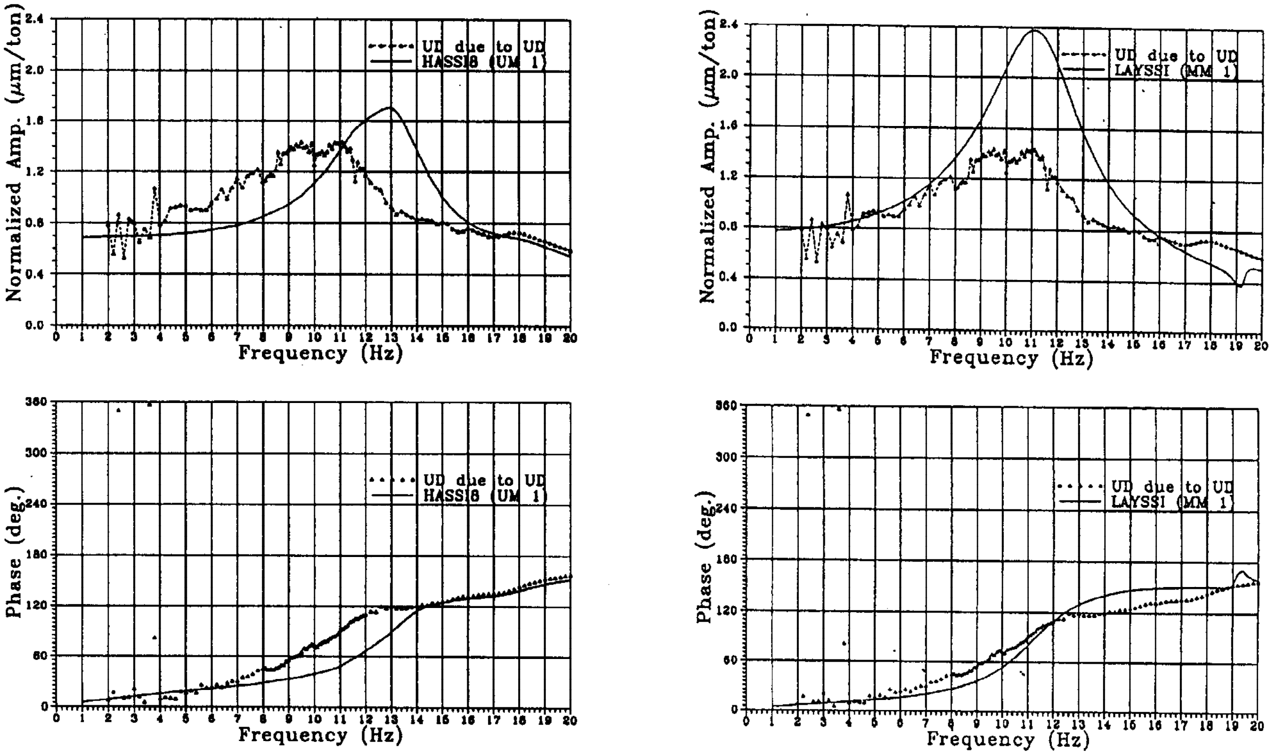

Fig. 6 Comparisons of roof vertical response in base vertical test